

Search for Excited Leptons at HERA

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Searches for excited electrons and neutrinos have been performed using the complete HERA I and II data samples collected by the H1 detector at $\sqrt{s} = 320$ GeV corresponding to an integrated luminosity of up to 435 pb^{-1} . In absence of a signal, the limits on the ratio of the coupling to the compositeness scale derived extend the excluded region to higher masses than has been possible in previous searches.

1 Introduction

Compositeness models [2] attempt to explain the hierarchy of masses in the Standard Model (SM) by the existence of a substructure within the fermions. Several of these models predict excited states of the known leptons. Excited leptons (F^*) are assumed to have the same electroweak SU(2) and U(1) gauge couplings, g and g' , to the vector bosons, but are expected to be grouped into both left- and right-handed weak isodoublets with vector couplings. The existence of the right-handed doublets is required to protect the ordinary light leptons from radiatively acquiring a large anomalous magnetic moment via the F^*FV interaction (where V is a γ , Z , or W). Considering only the electroweak interaction, the phenomenological model describes this interaction by the Lagrangian density:

$$L_{F^*F} = \frac{1}{2\Lambda} \bar{F}_R^* \sigma^{\mu\nu} [gf \frac{\vec{\tau}}{2} \partial_\mu \vec{W}_\nu + g' f' \frac{Y}{2} \partial_\mu B_\nu] F_L + h.c.$$

where the new weights f and f' multiply the standard coupling constants g and g' corresponding to the weak SU(2) and the electromagnetic U(1) sectors respectively. The matrix $\sigma^{\mu\nu}$ is the covariant bilinear tensor, τ are the Pauli matrices, $W_{\mu\nu}$ and $B_{\mu\nu}$ represent the fully gauge invariant field tensors, and Y is the weak hypercharge. The parameter Λ has units of energy and can be regarded as the compositeness scale. The relative values of f and f' affect the size of the single-production cross section, their detection efficiencies and also the branching ratios of excited leptons.

Excited electrons and neutrinos may be produced in electron(positron)-proton collisions at HERA via t -channel $\gamma(Z)$ or W^\pm gauge boson exchange. In the case of excited neutrinos, the cross section is much larger in e^-p collisions than in e^+p collisions due to the favourable valence u-quark and the helicity enhancement, specific to CC-like processes. Therefore the search for excited neutrinos uses only e^-p sample data with an integrated luminosity of 184 pb^{-1} . In the case of excited electrons, both e^-p and e^+p collision modes are used, corresponding to total integrated luminosity of 435 pb^{-1} .

2 Data analysis and results

Excited leptons ($l = e, \nu$) are searched for in the following decay channels: $l^* \rightarrow l\gamma$, $l^* \rightarrow lZ$, $l^* \rightarrow lW$. The final states resulting from the Z or W hadronic decays are taken into account

Search for e^* , ν^* HERA I+II ($\sqrt{s} = 320$ GeV, preliminary)

Selection	Data	SM	Efficiency \times BR
$e^* \rightarrow \nu W \hookrightarrow qq$	172	175 ± 39	~ 40 %
$e^* \rightarrow e Z \hookrightarrow qq$	351	318 ± 64	~ 45 %
$e^* \rightarrow e \gamma$	112	125 ± 19	60–70 %
$\nu^* \rightarrow \nu \gamma$	9	15 ± 4	50 %
$\nu^* \rightarrow e W \hookrightarrow qq$	198	189 ± 33	30–40 %
$\nu^* \rightarrow \nu Z \hookrightarrow qq$	111	102 ± 24	40 %
$\nu^* \rightarrow e W \hookrightarrow \nu \mu$	0	0.54 ± 0.04	3–4.5 %
$\nu^* \rightarrow e W \hookrightarrow \nu e$	0	0.6 ± 0.3	4–6 %
$\nu^* \rightarrow \nu Z \hookrightarrow ee$	0	0.12 ± 0.04	2 %

Table 1: Observed and predicted event yields for the event classes of e^* and ν^* searches. The selection efficiency for the signal multiplied by the branching ratio (BR) in each decay channel is also presented.

for both excited electrons and neutrinos and the Z or W leptonic decays are taken into account only for excited neutrinos. In the following, the selection criteria are described for the decay channels.

The $\nu^* \rightarrow \nu \gamma$ channel

Candidate events are selected by requiring missing transverse momentum $P_T^{miss} > 15$ GeV, where the photon is identified as an isolated electromagnetic (e.m.) cluster in the LAr calorimeter within a polar angle of 5° to 120° . The photon candidates measured within the acceptance of the central tracker ($\theta^\gamma > 20^\circ$) are required to have no associated tracks. The neutral current (NC) and charged current (CC) backgrounds are reduced by imposing the longitudinal momentum balance $E - P_Z > 45$ GeV for events with photon candidates at lower transverse momentum $P_T^\gamma < 40$ GeV and by requiring the virtuality (Q_γ^2) to satisfy $\log(Q_\gamma^2) > 3.5$ GeV². The background is further suppressed by rejecting events with a transverse momentum of the final hadronic in the calorimeter $P_T^h < 5$ GeV.

The $e^* \rightarrow e \gamma$ channel

Candidate events are selected with two isolated e.m. clusters in the LAr calorimeter of transverse energy greater than 20 GeV and 15 GeV, respectively, and with a polar angle between 5° and 130° . The sum of the energies of the two clusters has to be greater than 100 GeV. The background from NC is further suppressed by rejecting events with a total transverse energy of the two isolated e.m. clusters lower than 75 GeV.

The $e^* \rightarrow e Z, \nu W$ and $\nu^* \rightarrow e W, \nu Z$ channels with $Z, W \rightarrow qq'$

These channels use subsample of events with at least two jets with high transverse momentum $P_T^{j1(j2)} > 20(15)$ GeV reconstructed within $5^\circ < \theta^{j1(j2)} < 130^\circ$. The dijet invariant mass must be compatible with the relevant boson mass and should be closest to them.

Events with two high P_T jets and one electron: The channels $e^* \rightarrow e Z \hookrightarrow qq$ and $\nu^* \rightarrow e W \hookrightarrow qq$ are characterised by at least two high P_T jets and an energetic isolated e.m. cluster $P_T^e > 10$ GeV ($P_T^e > 20$ GeV for $e^* \rightarrow e Z \hookrightarrow qq$) in the polar angle $5^\circ < \theta^e < 130^\circ$. The

polar angle of the highest P_T jet resulting from W boson should be lower than 80° . The dijet invariant mass has to be greater than 60 GeV. If $P_T^e < 65$ GeV, the dijet invariant mass must be greater than 75 GeV. In the case of the $\nu^* \rightarrow eW_{\rightarrow qq}$ channel, to reduce the NC background, the polar angle of e.m. cluster must be lower than 90° . Furthermore, the background is reduced by requiring the virtuality computed from the e.m. cluster kinematics $Q^2 > 2500$ GeV² if $P_T^e < 25$ GeV and by requiring a third jet with $P_T > 5$ GeV to be present in the event if $P_T^e > 50$ GeV.

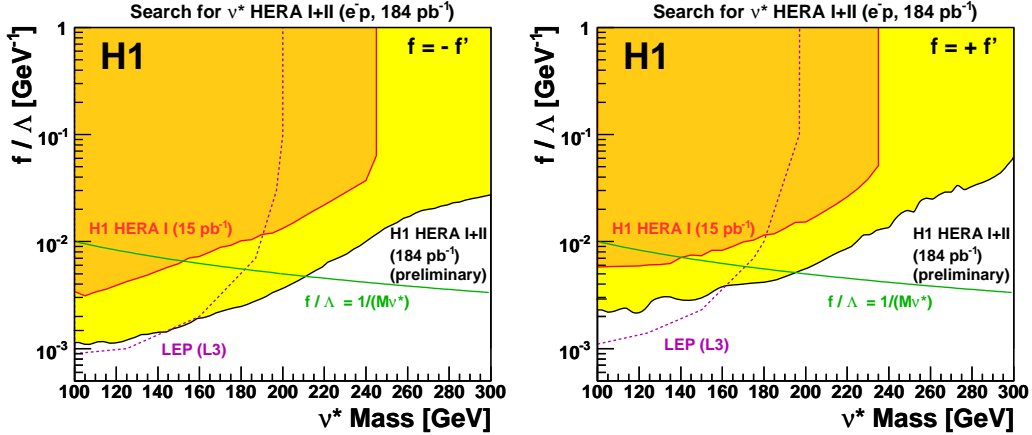


Figure 1: The 95% C.L. limits obtained for coupling constants (f/Λ) as a function of the excited neutrino mass within two assumptions: $f = -f'$ (left) and $f = +f'$ (right). The observed limits from this annalysis using all H1 e^-p data is presented by the yellow area. Values of the couplings above the curves are excluded. The orange-dark area corresponds to the exclusion domain published by the H1 experiment using 98/99 data and the dashed line to the exclusion limit from the L3 experiment at LEP [4].

Events with two high P_T jets and P_T^{miss} : The channels $e^* \rightarrow \nu W_{\rightarrow qq}$ and $\nu^* \rightarrow \nu Z_{\rightarrow qq}$ are characterised by at least two high jets and $P_T^{miss} > 12$ GeV. In the case of $e^* \rightarrow \nu W_{\rightarrow qq}$ channel, the ratio V_{ap}/V_p of transverse energy flow anti-parallel and parallel to the hadronic final state [3] is required to be lower than 0.3 to reject the photoproduction (γp) background. The dijet invariant mass is required to be greater than 50 GeV. Furthermore, if $P_T^{miss} < 65$ GeV the dijet is required to have an invariant mass above 65 GeV. In the case of the $\nu^* \rightarrow \nu Z_{\rightarrow qq}$ channel, a dijet invariant mass greater than 60 GeV is required. In order to reduce CC background, the total hadronic system is required to have a polar angle above 20° and a third jet with $P_T > 5$ GeV has to be present in the event if $P_T^{miss} < 65$ GeV. The longitudinal balance $E - P_Z > 25$ GeV is imposed if $P_T^{miss} < 50$ GeV. In addition, events with $P_T^{miss} < 30$ GeV are only accepted if the topological variable $V_{ap}/V_p > 0.1$.

The $\nu^* \rightarrow eW, \nu Z$ channels with $Z \rightarrow ee, W \rightarrow \nu e(\mu)$

Events with two electron and P_T^{miss} : These channels use a subsample of events with two high P_T isolated e.m. clusters $P_T^{e1(e2)} > 20(15)$ GeV and a polar angle $5^\circ < \theta^{e1(e2)} < 100^\circ(120^\circ)$ and $P_T^{miss} > 12$ GeV. The clusters are required to have associated tracks if they are measured within the acceptance of the central tracker.

Events with one muon and an electron: Candidate events containing an isolated muon plus an isolated electron, both having a high transverse momentum $P_T^{e(\mu)} > 20(10)$ GeV and a polar angle $5^\circ < \theta^{e(\mu)} < 100^\circ(160^\circ)$ are selected. A cut $P_T^{miss} > 12$ GeV is applied. The backgrounds are reduced by requiring the virtuality (Q_e^2) to satisfy $\log(Q_e^2) > 3$ GeV².

The observed number of events are compared to the expected SM background in table 1 for each search channel. A good overall agreement is found for all channels. No significant deviation is observed in the data. The selection efficiency for each decay channel for the both e^* and ν^* search is presented also in the table 1.

3 Interpretation and Conclusions

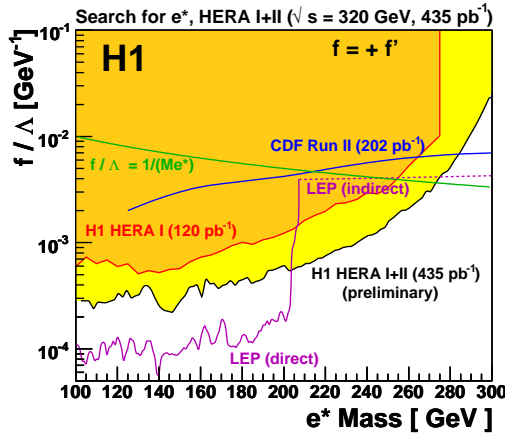


Figure 2: The 95% C.L. limits obtained for coupling constants (f/Λ) as a function of the excited electron mass within assumption: $f = +f'$. The observed limit from this analysis using 435 pb^{-1} of H1 data is presented by the yellow area. The orange-dark area corresponds to the exclusion domain published by the H1 experiment using HERA I data. The combined exclusion limit from LEP experiments is presented by the violet line. The result of the CDF [5] experiment at the Tevatron is also shown.

In absence of a signal for both excited electron and neutrino production, upper limits on the coupling f/Λ have been derived at 95% Confidence Level (C.L.) as a function of excited electron and neutrino masses. In case of excited neutrinos production, the obtained limits are displayed for the two assumptions $f = -f'$ and $f = +f'$ (figure 1). For $f = -f'$ (maximal $\gamma\nu^*\nu$ coupling) and assuming $f/\Lambda = 1/M_{\nu^*}$, excited neutrinos with masses below 211 GeV are excluded at 95% C.L. The limits on the ratio f/Λ also are given for the excited electron for the hypothesis $f = +f'$ (figure 2). We do not consider the case $f = -f'$, because the γe^*e coupling constant would be equal to zero and the production cross section of the excited electron is very small. For this hypothesis and assuming $f/\Lambda = 1/M_{e^*}$, excited electrons with masses below 273 GeV are excluded at 95% C.L.

References

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